

Inventors: Leo Anthony Almeida

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Title: Method and Apparatus for Multi-Spectral Photodetection

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GOVERNMENT INTEREST

The invention described herein may be manufactured, used, sold, imported, and/or licensed by or for the Government of the United States of America.

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FIELD OF INTEREST

This invention relates to an array of photodetectors consisting of rows or groups with distinct spectral responses.

BACKGROUND OF THE INVENTION

Conventional spectrometers utilize diffraction gratings or
10 similar elements to disperse a light signal. The diffraction
grating can be moved or scanned such that the dispersed light
signal is incident on a single photo detector. The detector is
chosen so that its spectral response is matched to that of the
incoming radiation and of the grating. As the diffraction
15 grating is moved in a step-wise fashion, distinct wave bands of
light are detected and a spectrum of the incident light intensity
is generated as a function of time. Alternatively, linear array
of photo detectors, all of which have identical photoresponse,

can be placed in the path of a dispersed light signal from a fixed
20 diffraction grating. However, these prior art devices cannot
process temporal, spatial and spectroscopic data simultaneously.

Accordingly, there is a need to have a temporal, spatial
and spectroscopic data simultaneously. The present invention
addresses this need.

25 SUMMARY OF THE INVENTION

Accordingly, one object of the present invention is to
provide a multi spectral photodetector that provides temporal,
spatial and spectroscopic data simultaneously.

This and other objects of the present invention are
30 achieved by providing for a multispectral focal plane array which
includes an array of photodetectors having individual
photodetectors which have a distinct spectral response; and an
integrated circuit coupled to the array, wherein the integrated
circuit collects electrical signals from the individual
35 photodetectors. The photodetectors are fabricated from ternary
or quaternary compound semiconducting materials whose band-gap
varies via a grading of the chemical composition of the
photodetector. The grading of the semiconducting material and
the varying height of the photodetectors determine the distinct
40 spectral response of the photodetectors.

The photodetector array according to the present invention
acquires temporal, spatial and spectroscopic data

simultaneously. This eliminates the need for dispersive optical elements when used either in a spectrometer (see Figure 1b) or spectral imager (see Figure 2b). The elimination of dispersive optical elements leads to a higher light throughput for optical systems.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other objects of the invention will become readily apparent in light of the Detailed Description of the Preferred Embodiment and the attached drawings wherein:

Figures 1a and b are schematic representations of a photodetector arrays. Figure 1a is a representation of a conventional linear photodetector array. Figure 1b is a representation of a linear multispectral photodetector array according to the present invention.

Figures 2a and b are schematic representations of a hyperspectral imaging application using 2 dimensional multispectral photodetector arrays. Figure 2a shows a conventional 2-dimensional photodetector array used in the hyperspectral imager and Figure 2b is a representation of a two-dimensional multispectral photodetector array according to the present invention

Figures 3a-3c show the epitaxy and photolith steps to form an epitaxial layer of a compound semiconducting material that is

the basis of the multi-spectral photodetector array according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

5 The multi-spectral imager/spectrometer according to the present invention includes a two-dimensional array of photodetectors, which detect photons (light) and generate electric signals proportional to the flux of incident photons. This array is coupled to an integrated circuit, which collects
10 electrical signals from the individual pixels. Furthermore, in this array any given row or group of rows is preferentially sensitive to distinct wavebands (colors) of light. Using this array, light can be spectrally analyzed without the use of a diffraction grating or similar dispersive optical element.
15 Additionally, this array may be utilized as a scanning focal plane array to image a scene in multiple wave bands (hyperspectral imager). Depending on the compound semiconducting material system used to fabricate the multi-spectral imager/spectrometer, a wide variety of wavelengths of
20 light may be analyzed from long wavelength (12 μ m) infrared (using HgCdTe) to ultraviolet (using AlGaIn).

Figure 1b is a representation of a linear multispectral photodetector array according to the present invention. The multispectral photodetector array includes a two-dimensional

array of photodetectors, either photodiodes or photoconductors, coupled to a read out integrated circuit, whose function is to collect electrical signals from individual pixels. Such an array differs from a conventional array in that each row or
5 group of rows in the array has a distinct spectral response. The size of the array is arbitrary and may be chosen to suit the needs of specific applications. The upper size limit is dictated primarily by that area of suitable semiconducting material that is available, as well as limitations imposed by
10 conventional semiconductor device processing methods.

In the present invention, the signal from each individual pixel of the linear array corresponds to a distinct spectral response. According to the present invention, each pixel has a broadband response and it is the cut-off of the broadband
15 response that varies across the array. Because there are no moving parts, this configuration provides faster data acquisition and a more mechanically robust system.

In order to generate a spectral image of a scene (i.e. simultaneously acquire spectral and spatial data), a two-
20 dimensional array of such photo detectors is placed in the path of a dispersed light signal from a fixed diffraction grating such that each row of pixels detects a distinct waveband. Such a system is pictured schematically in Figures 2b. A mirror is moved in a step-wise fashion to scan the scene and generate

spatial information. For one complete cycle of the mirror's motion, corresponding to one scan line of the scene, the signals from each column generate spatial data.

A diffraction grating or a similar dispersive optical element is necessary for conventional spectrometers and spectral imagers. The design and construction of optical elements; particular care must be taken to align such elements. Furthermore, the use of diffraction gratings leads to a loss of light intensity due to higher order diffraction bands.

The multispectral photodetector array derives its functionality from the inherent opto-electrical properties of ternary and quaternary compound semiconducting materials. Its fabrication is facilitated by advanced epitaxial technology (band gap engineering), which allows precise control over the thickness and chemical composition of deposited compound semiconductors. Semiconducting material absorbs photons with energies greater than a certain energy, which is a characteristic of a given material; this characteristic energy is known as the band gap energy. The material is transparent to photons with energies less than the band gap energy.

Furthermore, for a ternary (or quaternary) compound semiconducting material system, such as $\text{Hg}_{1-x}\text{Cd}_x\text{Te}$, the band gap varies with chemical composition (x value). Therefore, by changing the chemical composition of a material in a deliberate

manner, one can control the band gap and therefore, the spectral response of the material.

The basis of the multi-spectral photodetector array is an epitaxial layer of a compound semiconducting material, whose composition varies in the direction of growth in either a graded or stepped fashion (Figure 3a Step 1). A continuously graded composition of the epilayer is required for a multi-spectral photodetector array with each row corresponding to a distinct spectral response (Figure 3a). A stepped compositional profile in the epilayer is required for a multi-spectral photodetector array with groups of rows corresponding to distinct spectral response (right Figure 3b). The number of compositional steps in the epilayer determines the number of groups of rows with distinct spectral responses. For a backside illuminated configuration, the composition is graded such that material with the largest bandgap is deposited first and subsequently smaller bandgap material is deposited. Once the epilayer is deposited, it is then processed using standard photolithographic techniques.

The first and most crucial of the device processing steps entails creating a wedge or stepped wedge shape across the entire area of the focal plane array (Figure 3b). The direction of the wedge determines the orientation of the rows and columns. For example, in the cross-sectional diagram of Figure 3b, rows

of detectors will be oriented perpendicular to the plane of the page, while columns will be parallel to the plane of the page, running horizontally. Once the wedge is created and orientation of the rows and columns is determined, standard semiconductor
5 processing steps are used to delineate individual photodetectors.

Spectral information from the array is compiled based on the fact that progressively longer wavelengths of light will be absorbed in consecutive rows containing material with smaller
10 band gaps. In Figures 3a and b, pixels (or rows of pixels) toward the left hand side of the Figure absorb longer wavelengths of light. Additionally, any given pixel absorbs virtually all of the light absorbed by its neighboring pixel to the right. Therefore, the difference in signals between
15 consecutive rows provides spectral information.